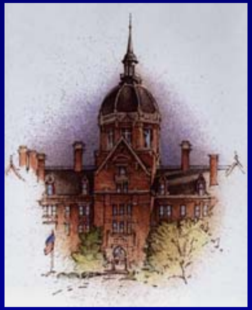
NIBIB/MMC WORKSHOP

Defining the State-of-the-Art in Biomedical Imaging: Research Needs for the Future

Session #3

Data Reconstruction, Interpretation, and Informatics



RESEARCH NEEDS FOR

DATA/IMAGE RECONSTRUCTION

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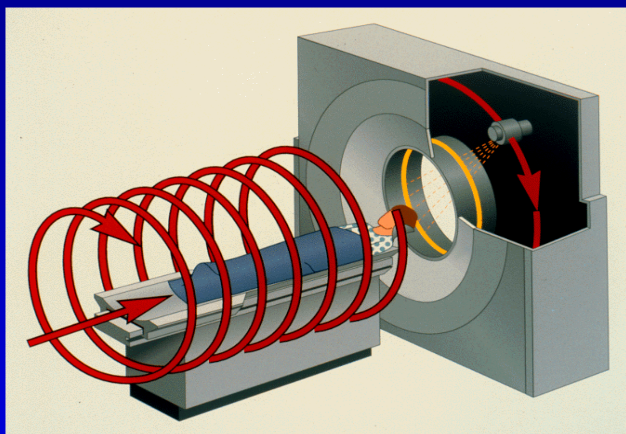
Johns Hopkins University

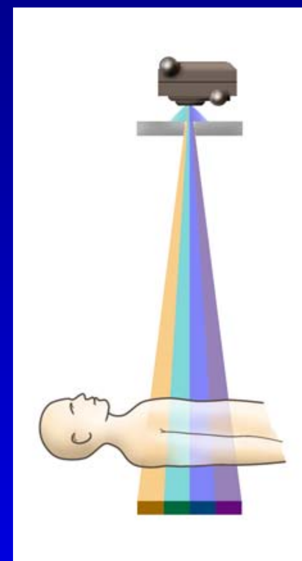
IMPORTANCE OF DATA/IMAGE RECONSTRUCTION

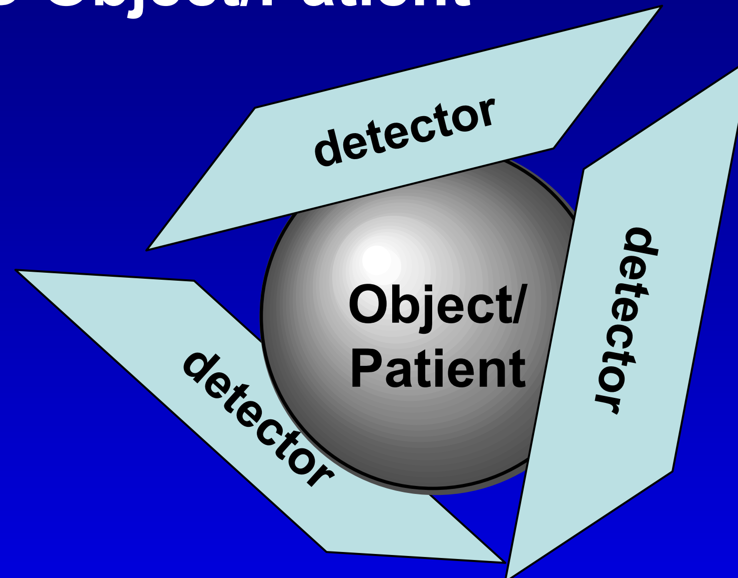
- A major goal of biomedical imaging is to seek accurate 3D or 4D information of patients or, more recently, of small animals using
  - e.g., x-ray CT, PET, SPECT, MRI, US, Optical
- 3D and 4D imaging techniques often involves special data/image acquisition geometries and strategies, and reconstruction methods

MEDICAL IMAGING PROCESS

4D Data Acquisition of 3D Object/Patient







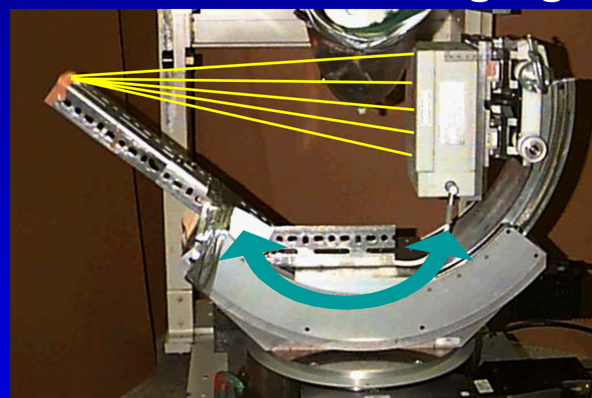
Data/Image Reconstruction

Reconstructed Images

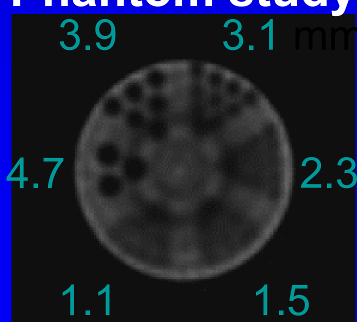
Application Specific **EMISSION** & Transmission Tomography (ASETT) of the Breast

Compact Hemispherical System for ECT

3D Cone Beam Transmission Imaging



Phantom study

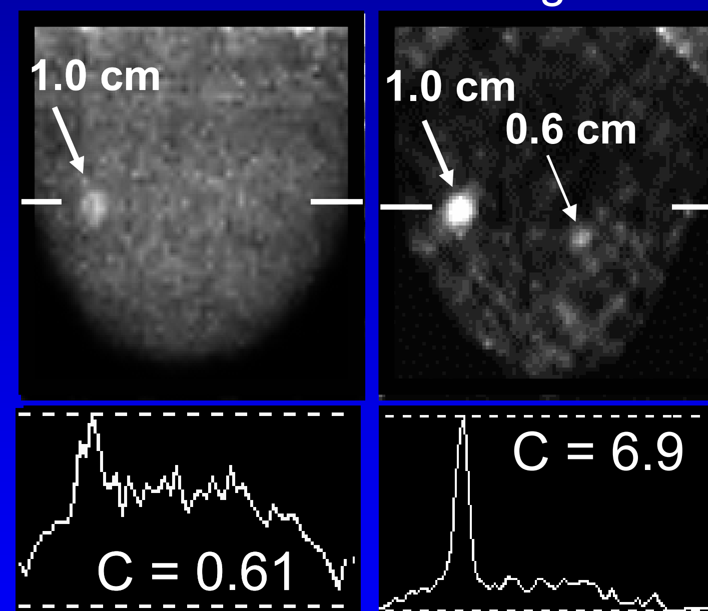


OSEM, 20 iterations, 8 subsets
256 projection angles

Comparison

Planar
Cranio-caudal

ASETT
Sagittal



11 times higher Contrast with ASETT

NIH 5R01-CA96821 and Whitaker RG-99-0305
Duke University Medical Center

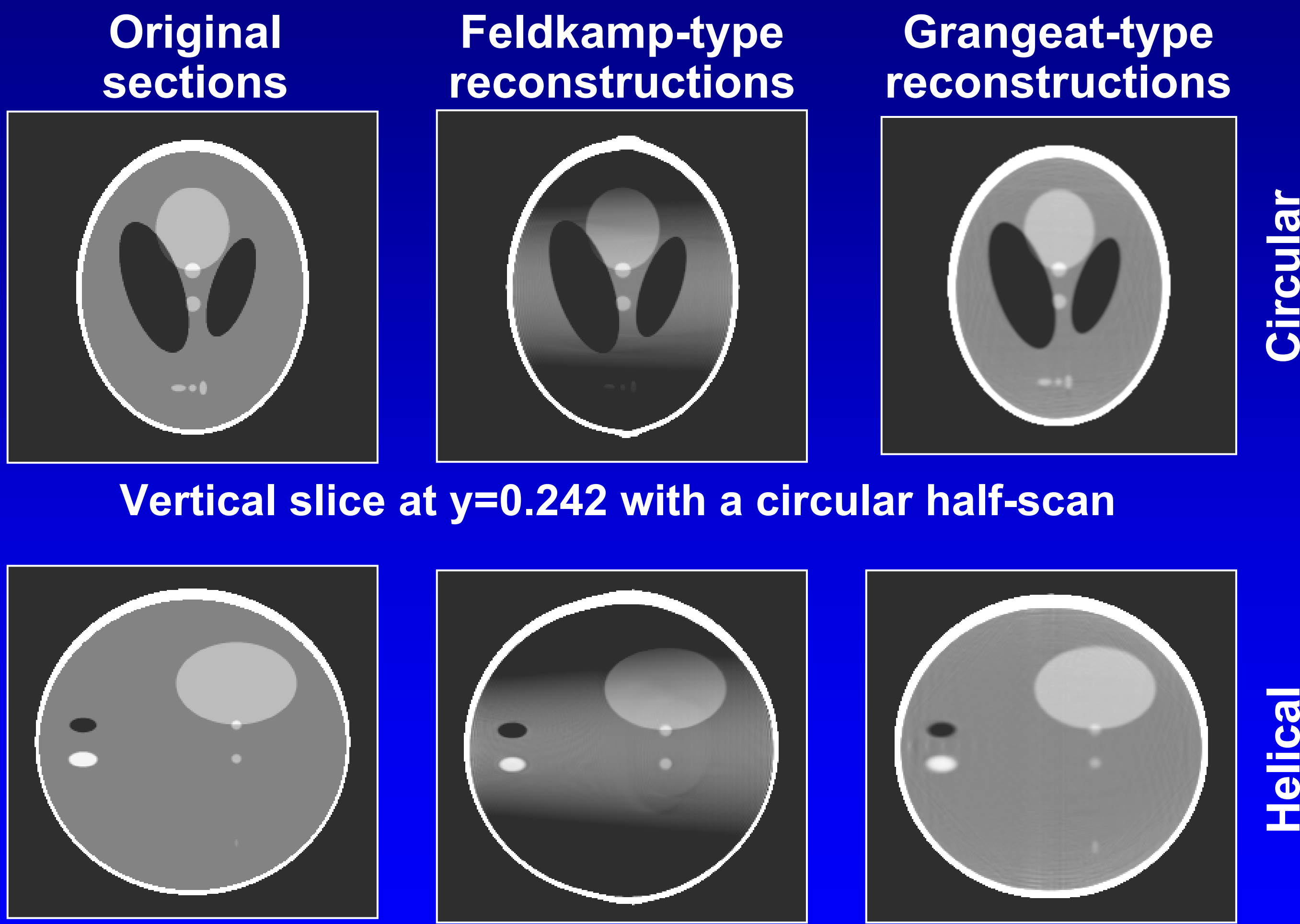
IDEAL CHARACTERISTICS OF DATA/IMAGE RECONSTRCTION

- Based on sound theoretical basis
  - Analytical or statistical based
- High quantitative accuracy
  - Reconstructed images are close representations of the “truth”
- Good noise handling properties
  - Reconstructed images with low noise levels and good noise properties
- High computational speed

PROBLEMS

- Accurate 3D & 4D reconstructed images are difficult to achieve due to
  - Noise
  - Lack of accurate analytical reconstruction methods
    - Especially for special acquisition geometries
  - Image degrading factors
  - Imaging system misalignments, especially in small animal imaging systems

Grangeat-Type Helical Half-Scan 3D Reconstruction of the 3D Shepp-Logan Phantom



Vertical slice at x=-0.0369 with a helical half-scan (Contrast range: 1.005-1.05)

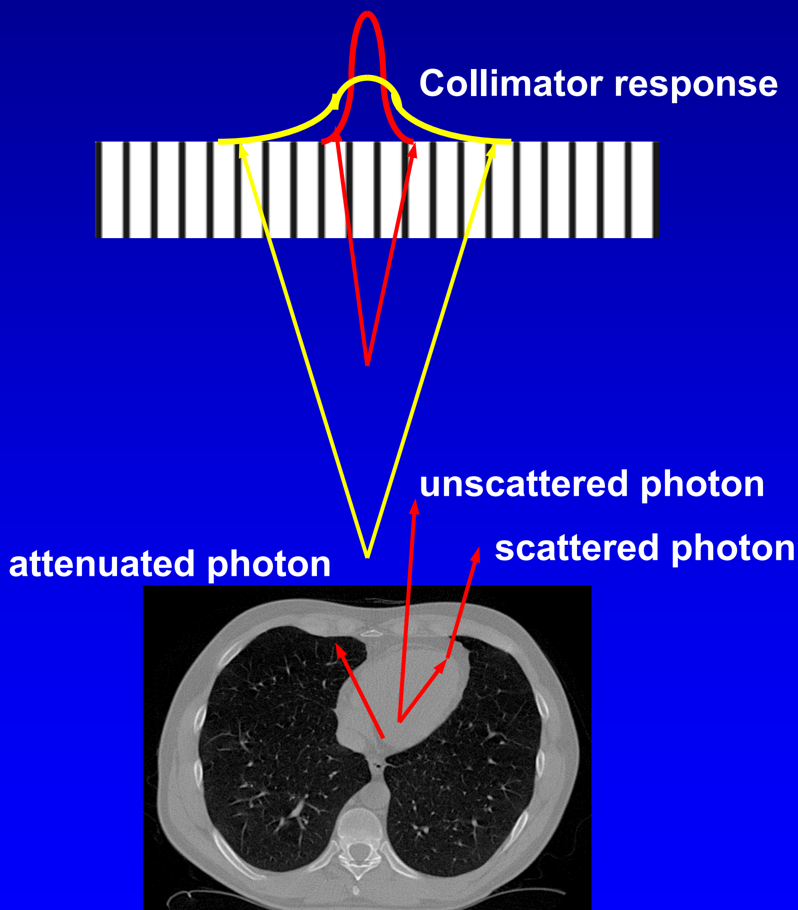
Lee SW, Wang G. SPIE Medical Imaging, San Diego, CA, 2003

Wang G, Lee SW: A Grangeat-Type Half Scan Algorithm for Cone-Beam CT (patent pending)

IMAGE DEGRADING FACTORS

Instrumentation

collimator, detector



Physical factors

attenuation, scatter, beam hardening

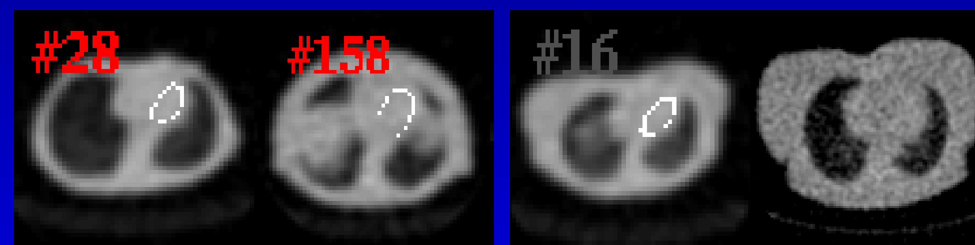
Patient Anatomy

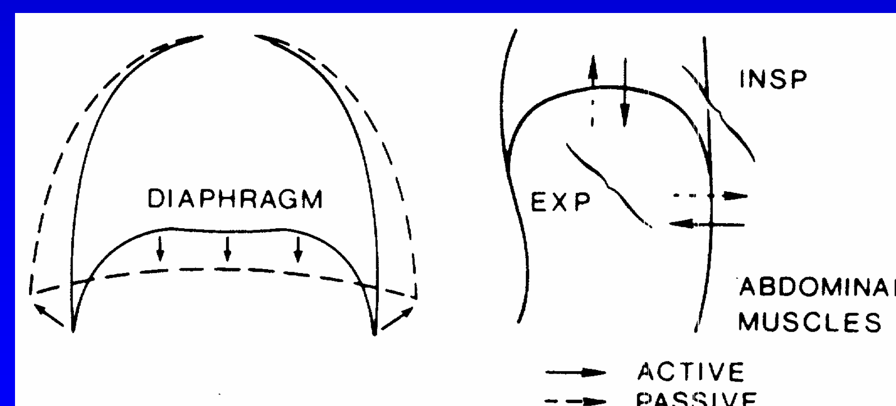
attenuation distribution, body shape

Male – Flat Diaphragm

Male – Raised Diaphragm

Female – Large Breasts, Flat Diaphragm





Patient Motion

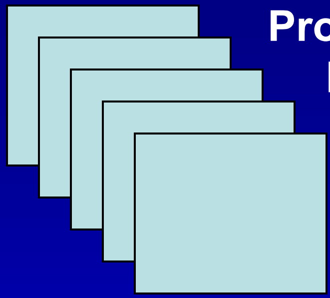
respiratory motion, upward creep

DIFFICULTIES IN COMPENSATING DEGRADING FACTORS

- Instrumentation
  - System non-uniformity, non-linearity
  - Non-stationary collimator-detector response
- Physical factors
  - Poisson statistics
  - Positron range, non-colinearity
  - Non-uniform attenuation in the chest region
  - Non-stationary & complex scatter response
  - Beam hardening
- Patient anatomy
  - Variations in body size, shape and structures
- Patient motions
  - Involuntary & voluntary motions

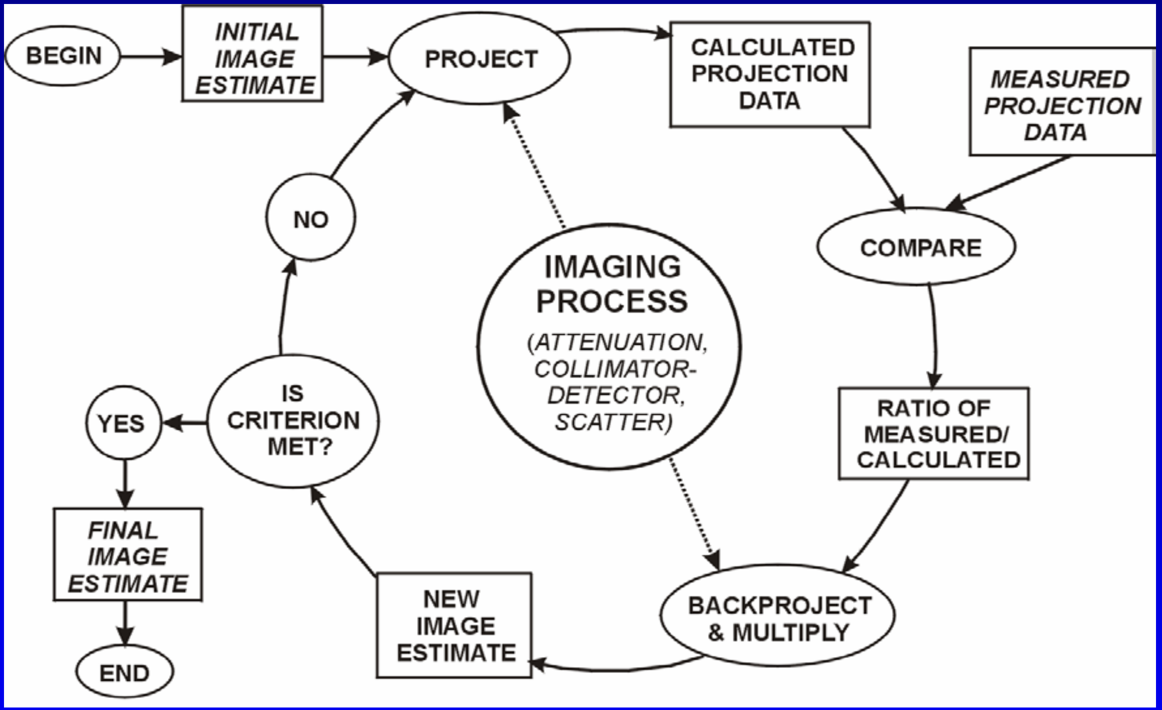
Exact compensation and pursue of true object distribution by theoretical means are difficult if not impossible to achieve

QUANTITATIVE RECONSRUCTION METHODS

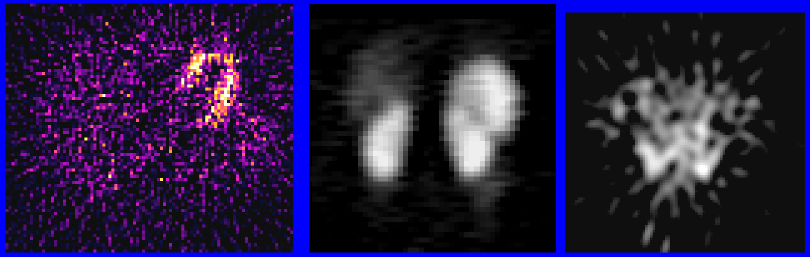


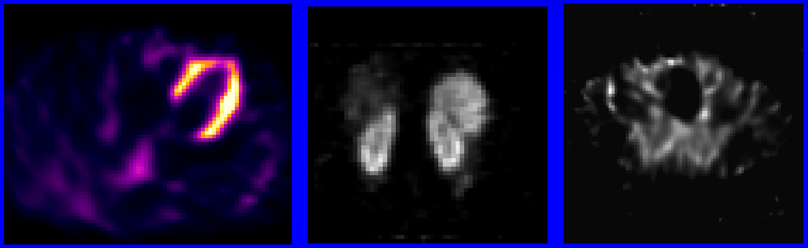
Projection Data

3D Iterative reconstruction methods with accurate 3D model of imaging process

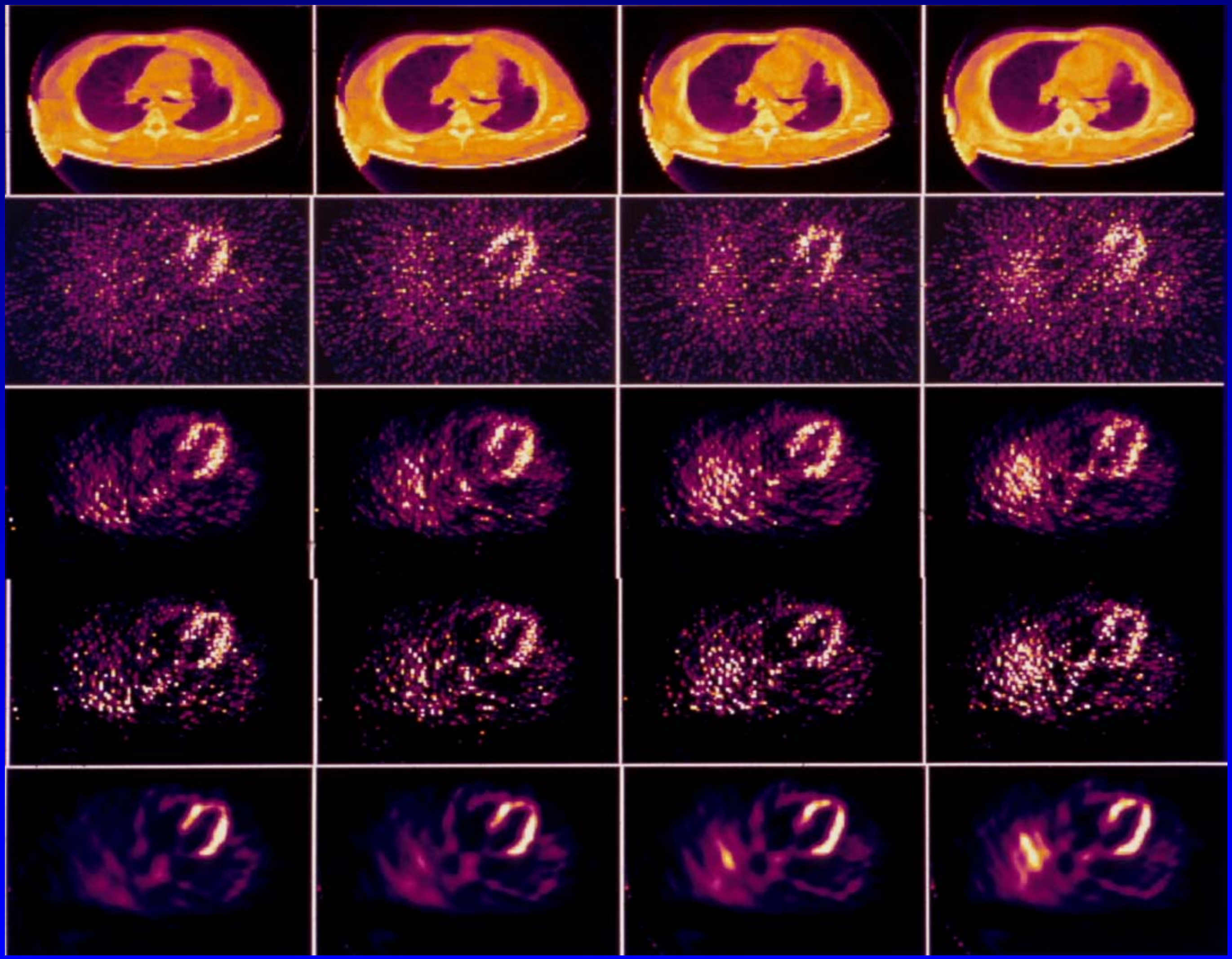


Analytical FBP method without any compensation





CLINICAL MYOCARDIAL PERFUSION SPECT



XCT

FBP
w/o comp.

3D OS-EM w/
Atten. Comp.

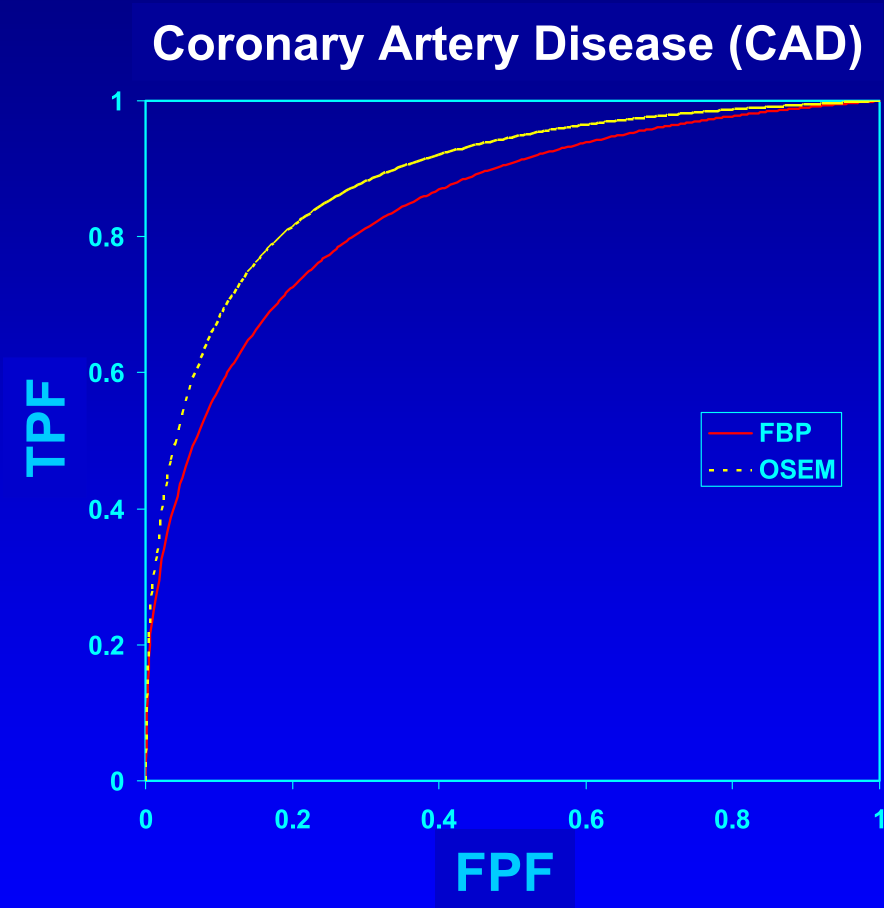
3D OS-EM w/
Atten. & scatter
Comp.

3D OS-EM w/
Atten., scatter
& CDR comp.

Data obtained using GE Hawkeye SPECT system with X-ray TCT at
Vanderbilt University, JA Patton, Ph.D. and processed at UNC-CH, EC Frey, Ph.D.

MYOCARDIAL PERFUSTION SPECT

FBP versus iterative OSEM



Continuous Rating Scale

Reconstruction Methods	AUC
FBP *(w/ all information)*	**0.852 ± 0.032**
OSEM *(w/ all compensation)*	**0.894 ± 0.031**

p = 0.0097

Previous results

AUC	FBP	AC	AC+SC	AC+SC+RC
	0.808	0.845	0.868	**0.894**

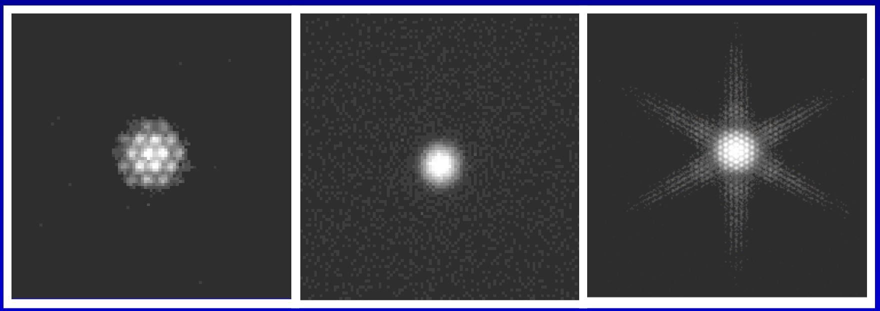
King, Pretorius, Narayanan et al., Univ. of Massachusetts

Narayanan et al, J. Nucl. Med., vol. 43, 3P, 2002.

RECONSTRUCTION WITH COMPENSATION FOR INSTRUMENTATION EFFECTS

Medium- & High-Energy Collimators

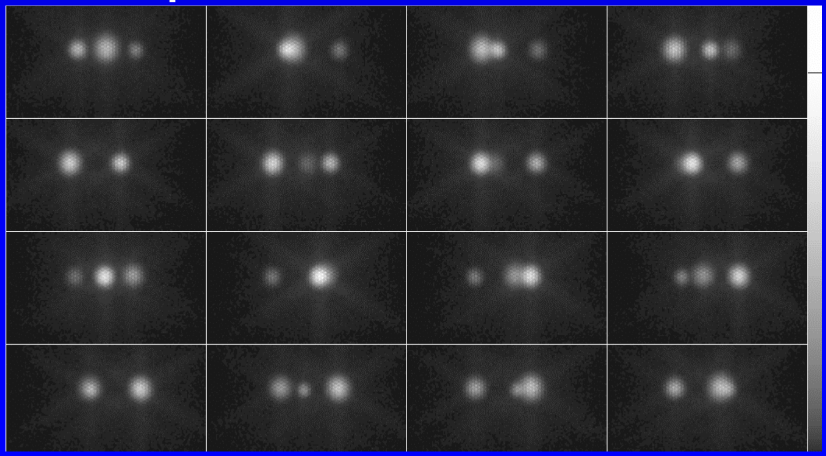
GE MEGP | Siemens ME | Siemens HE



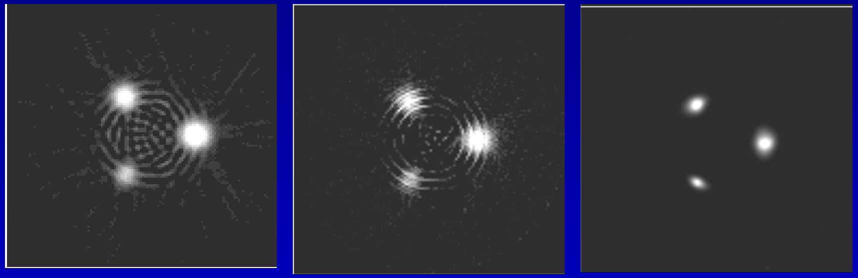
185 keV | 185 keV | 364 keV

Photon Energy

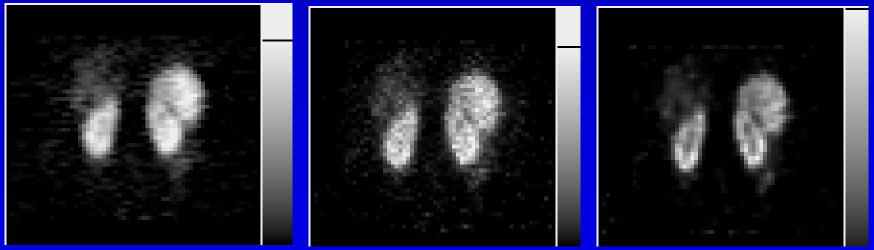
Sample Projection Images of 3 I-131 filled spheres obtained w/ Siemens HE



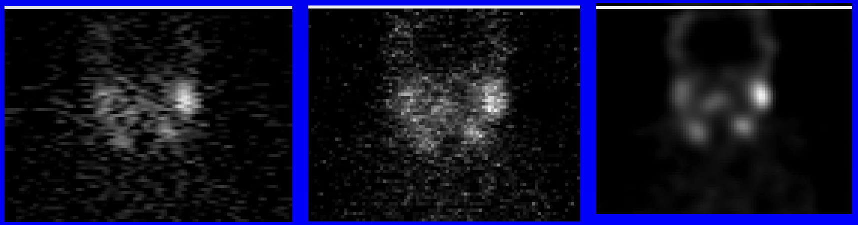
Phantom with 3 spheres



Patient In-111 Octreotide Study

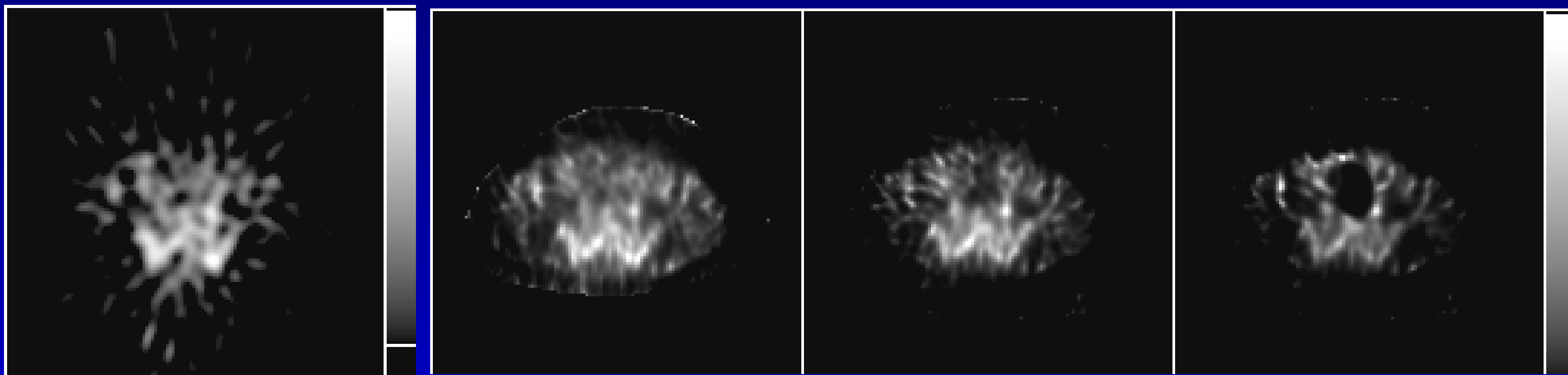


Patient I-131 Study



FBP w/o comp. | OS-EM w/o comp. | OS-EM w/ CDR comp.

In-111 PROSTASCINT® PROSTATE PATIENT STUDY (#12)



3D FBP
w/o correction
Butterworth, n=8, fc=0.15/p

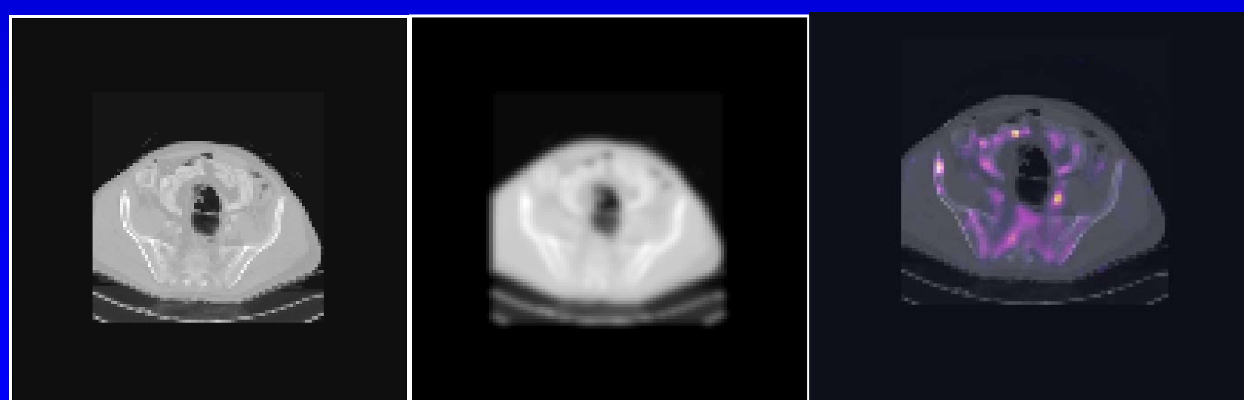
OS-EM, 2 it.
w/ CDR correction
correction

OS-EM, 3 it.
w/ CDR, attenuation
correction

OS-EM, 5 it.
w/ CDR, attenuation
& scatter correction

71 yr old white male w/ post bilateral nerve sparing prostatectomy in 1996 & recent increased PSA

SPECT images show asymmetric radiotracer focus at the left common iliac vessel raises suspicion for lymph node involvement



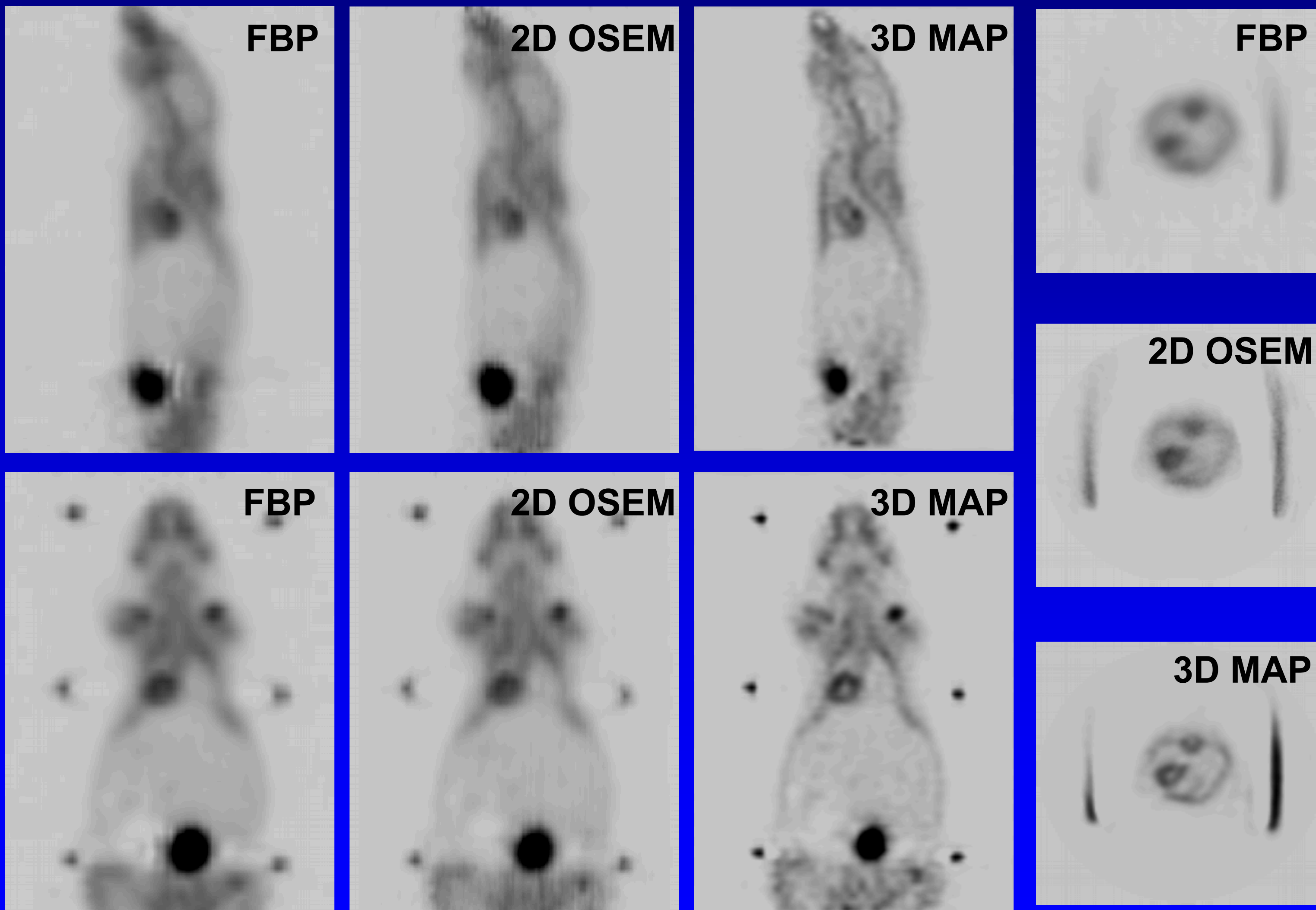
Original CT

Transformed attenuation map

Fused CT & SPECT image

Slice #55 ~12,573 counts/slice

MOUSE IMAGES FROM microPET I



FBP
ramp filter
w/o
compensation

2D OSEM
w/o
compensation

3D MAP
w/ compensation
of positron range,
co-linearity,
detector response

Date courtesy of Richard Leahy, Ph.D., University of Southern Carlifornia

SPECT RECONSTRUCTION USING HIGH-RESOLUTION ANATOMICAL INFORMATION

MR Image Slice

SPECT Reconstruction Using a Segmentation of the MRI

Initial SPECT Estimate Using MRI Regions

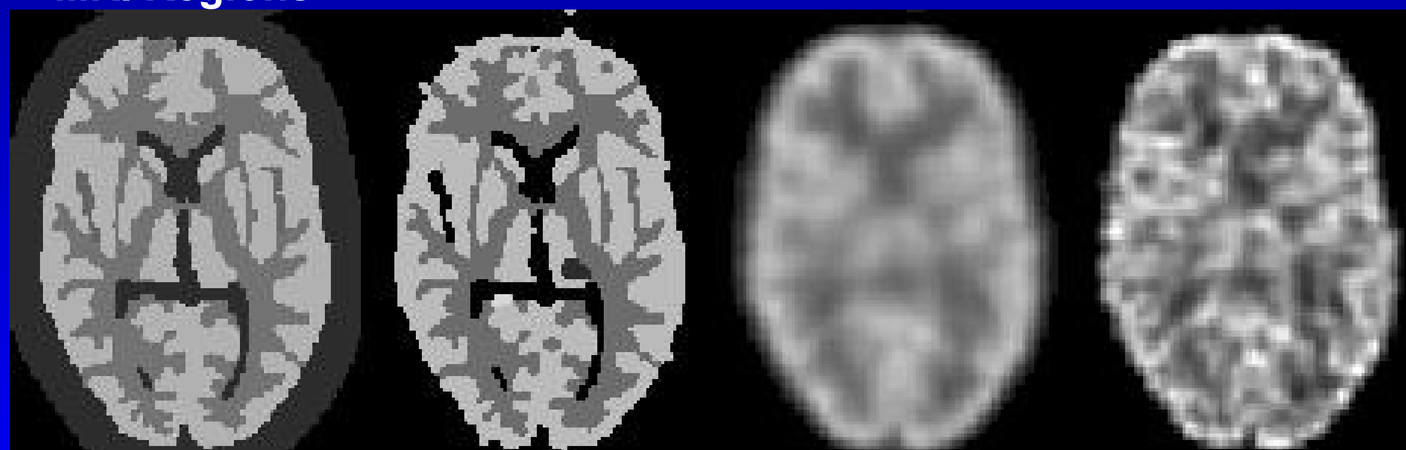
SPECT Estimate At Convergence

ML-EM Reconstruction

Iteration Number

50

400



Improved quantitative accuracy of total lesion activity reduction in the white matter area is realized when anatomical information is utilized (87,000 +/- 11,000 events versus the true value of 93,000 +/- 5,000).

JE Bowsher, VE Johnson, TG Turkington, RJ Jaszczak, CE Floyd Jr., RE Coleman. IEEE Trans Med Imag 15 (1996) 673-686.
Department of Radiology and Institute of Statistics and Decision Sciences, Duke University.
Supported by the Whitaker Foundation and by NIH Grants R29-CA56671 and S10rr04176-01

PINHOLE/CONE-BEAM IMAGING GEOMETRY

Parameters

ρ: skew angle of the AOR

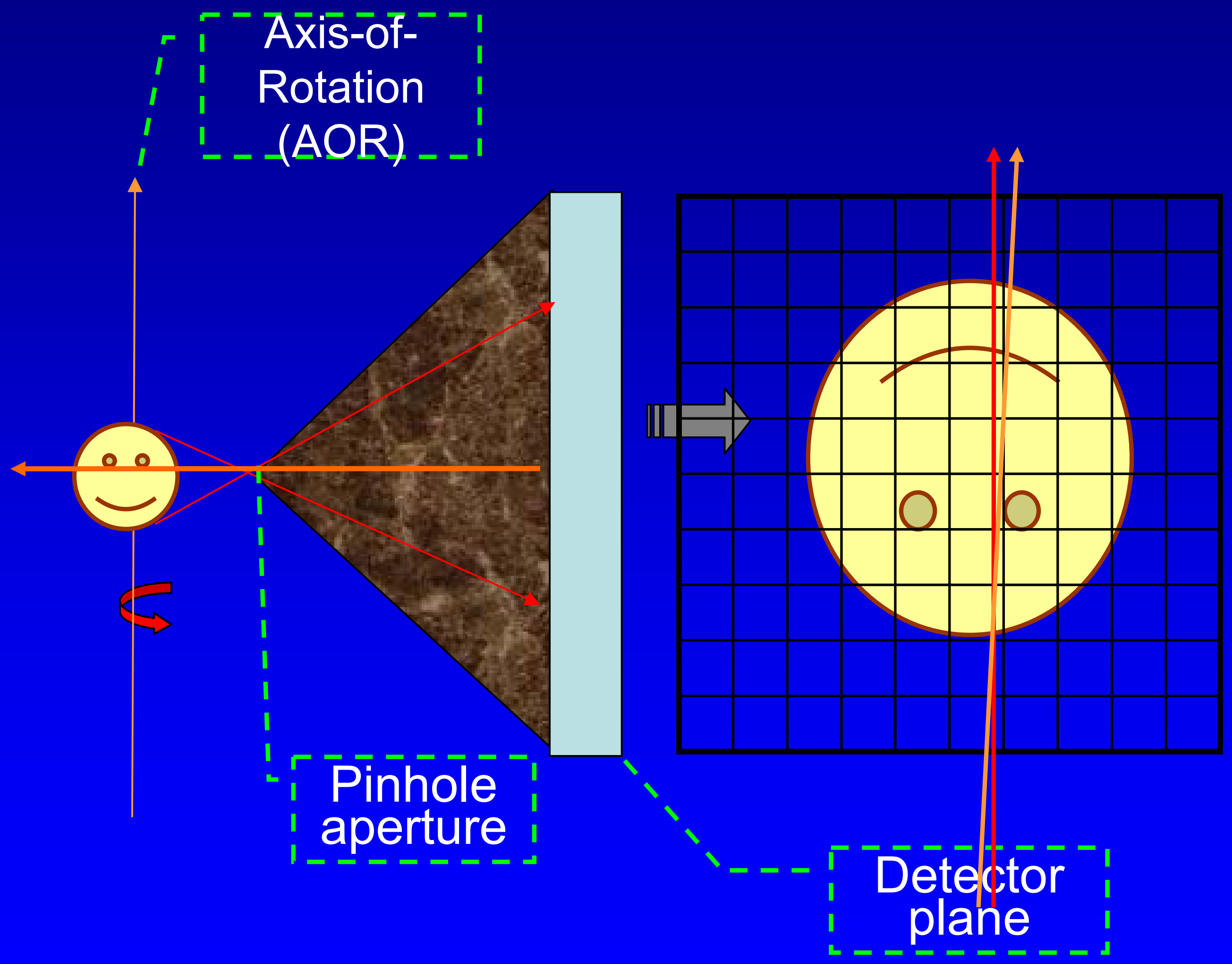
τ: tilt angle of AOR

X_{AO}: transversal shift of the AOR

Z_A: distance from the AOR to the detector plane

Z_F: shortest distance from the focal point to the detector plane

***X_F*, Y_F**: shifts of the focal point in the world coordinates with respect to the detector

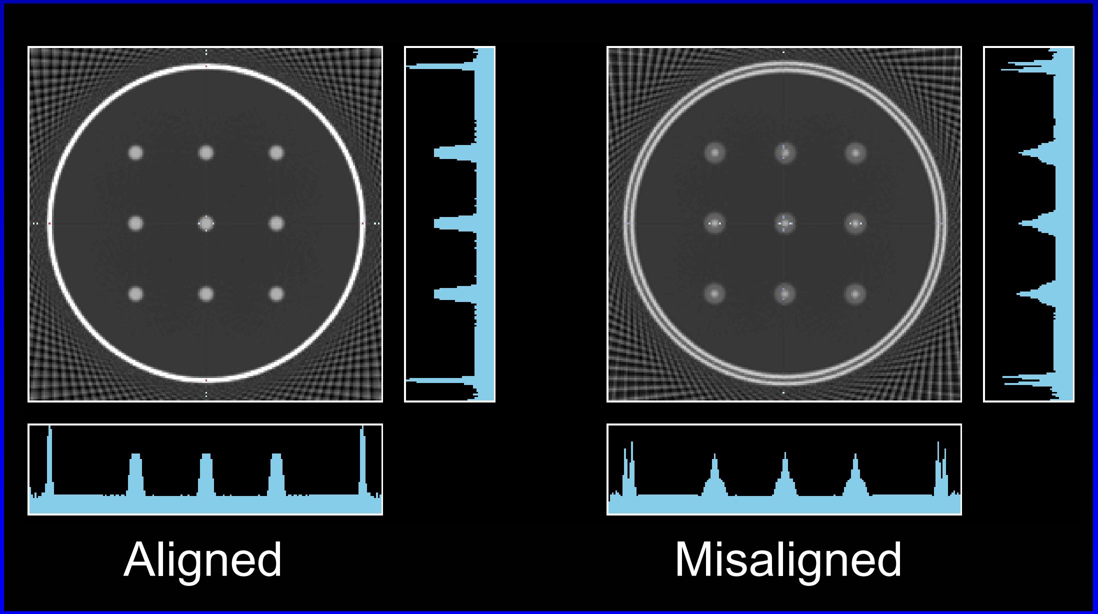


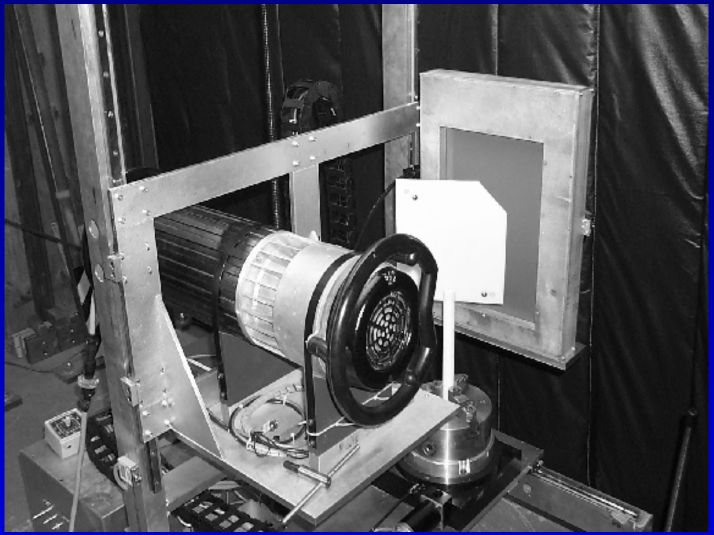
PARAMETER ESTIMATION IN CONE-BEAM CT IMAGE RECONSTRUCTION

Possible artifacts

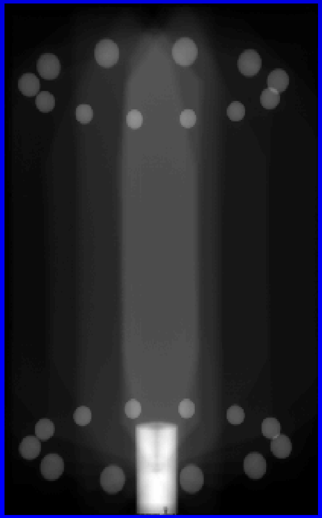
loss of resolution and structure alteration

(e.g. double walls)





Prototype x-ray CB-CT scanner at the I.N.E.E.L.

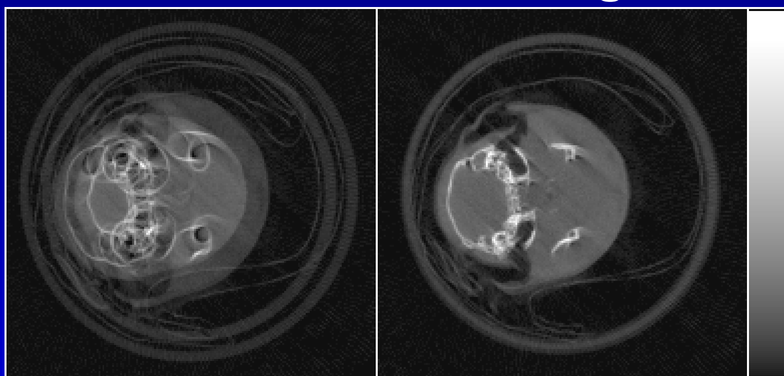


Sum of 12 projections over 360 deg.

Data courtesy of Frederic Noo, Univ. of Utah

ESTIMATION AND CORRECTION OF MISALIGNMENTS IN IMAGE RECONSTRCTIONS

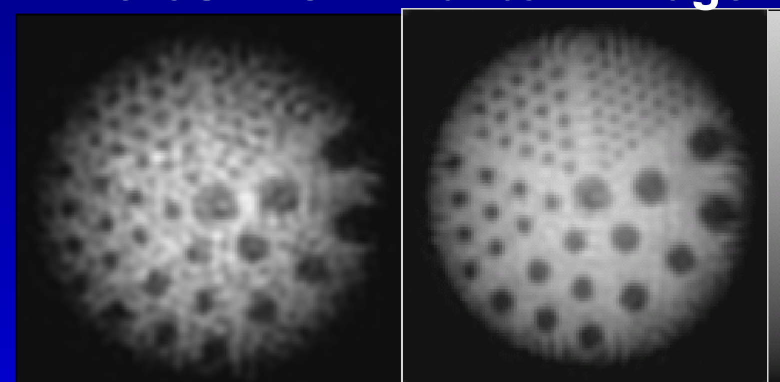
MicroCT Mouse Image



Misaligned
$\tau \sim 0.23^{\circ}$

Aligned

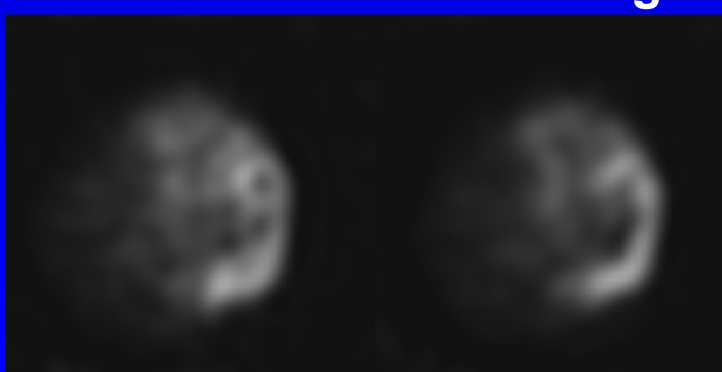
MicroSPECT Phantom Image



Misaligned
$X_{AO} \sim 0.8$ mm

Aligned

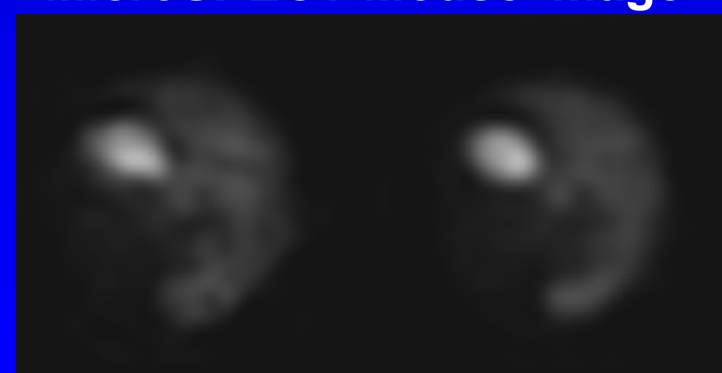
MicroSPECT Mouse Image



Misaligned
$X_{AO} \sim 0.2$ mm

Aligned

MicroSPECT Mouse Image



Misaligned
$X_{AO} \sim 0.2$ mm

Aligned

VALIDATION/EVALUTION --- *Simulation Tools*

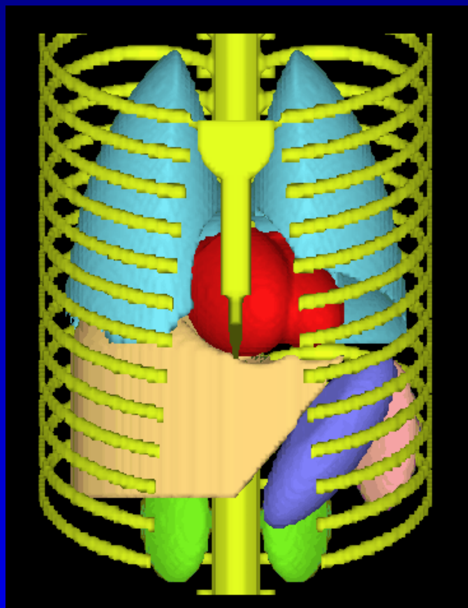
- Validation/Evaluation of reconstruction methods is Important in their development
- Advantages of simulation methods for validation
  - Known "truth" (as compared to clinical studies where truth is often unknown)
  - More flexible (as compared to physical phantoms)
- Limitations of simulation methods
  - Unrealistic computer generated phantoms
  - Inaccurate simulated projection data

ADVANCES IN SIMULATION TOOLS

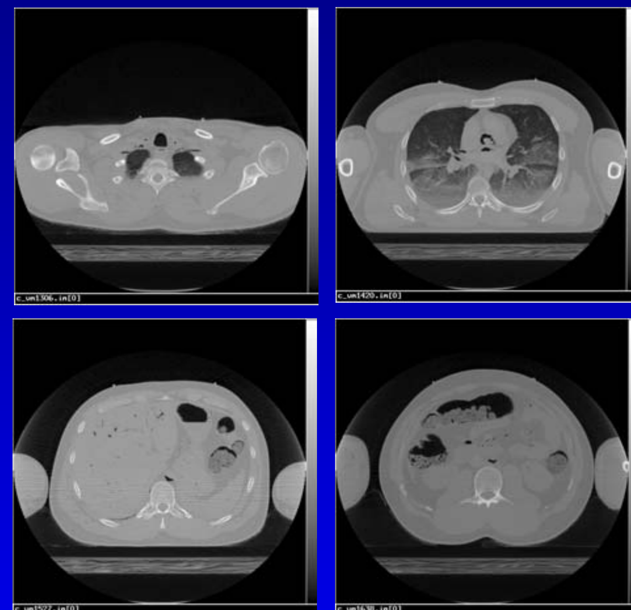
- Realistic anatomy based on
  - Clinical image data
  - Visible Human data
- New 4D computed generated phantoms
  - Beating heart based on 4D tagged MRI data
  - Respiratory motion based on respiratory gated 4D CT data
- Accurate projection data
  - Monte Carlo simulation techniques
  - Accurate models of instrumentation & imaging processes

NURBS-based Cardiac-Torso (NCAT) Phantom

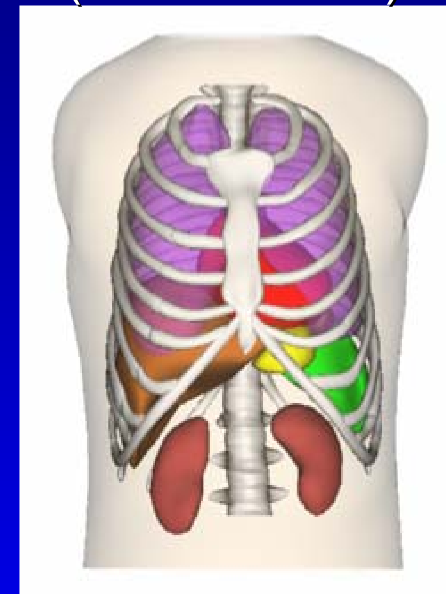
Previous MCAT Phantom



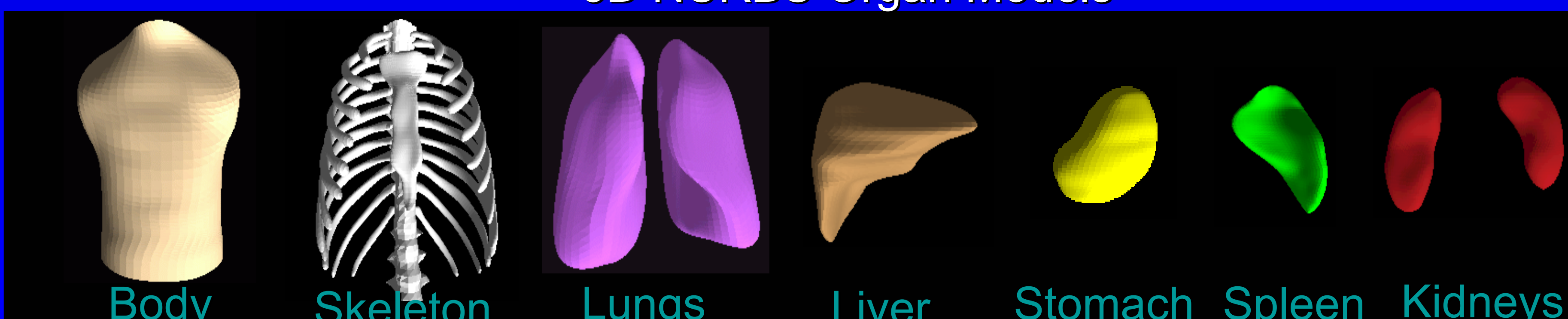
Sample Slices from the Visible Human CT Data Set



NCAT Phantom (anterior view)



3D NURBS Organ Models



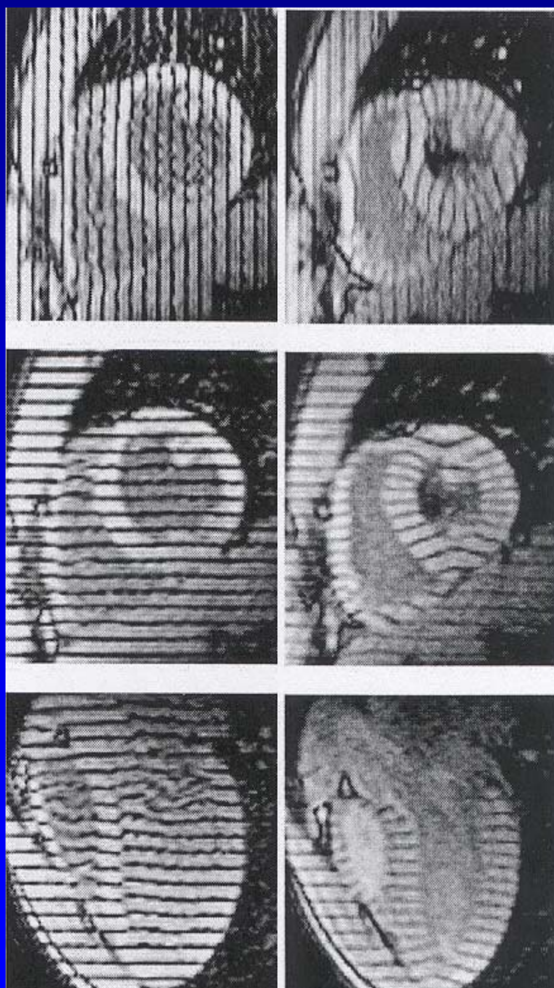
4D NCAT Phantom with Beating Heart and Respiratory Model

Diastole Systole

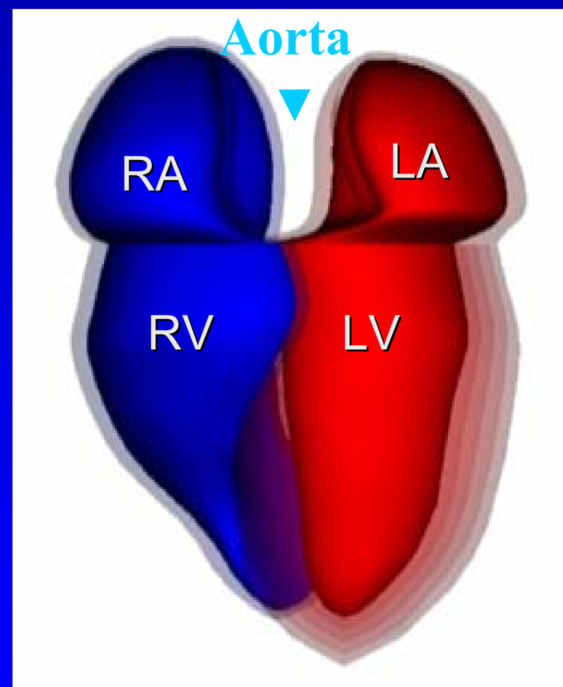
short axis slice (x)

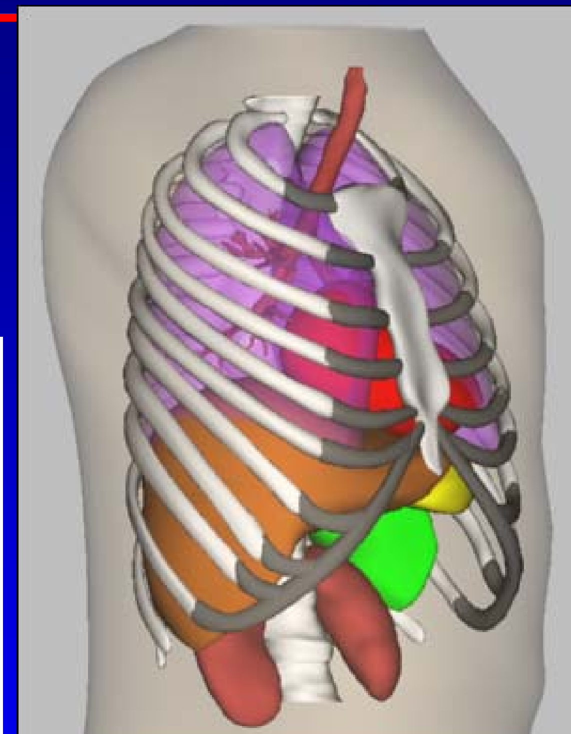
Ortho-gonal short axis slice (y)

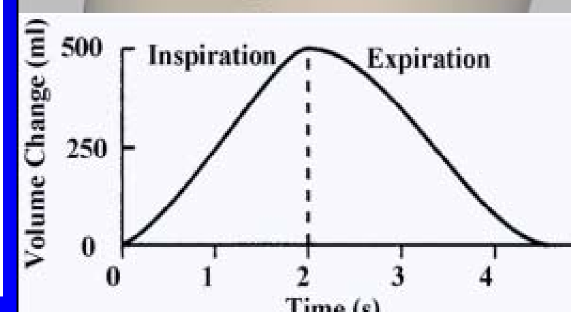
long axis slice (z)



Animated Motion Derived From Tagged Data







Tagged MRI data courtesy of Elliott McVeigh, Ph.D., NIH and Johns Hopkins University

Respiratory gated 4D CT data courtesy of Eric Hoffman, Ph.D., University of Iowa

FUTURE RESEARCH NEEDS IN DATA/IMAGE RECONSTRUCITON

- 3D, 4D & 5D Reconstruction methods for special data acquisition geometries and strategies
- Reconstruction methods that compensates for image degrading factors
- Parameter estimation and calibration methods for high-resolution image reconstructions
- Validation methods --- Simulation tools

FUTURE RESEARCH NEEDS IN DATA/IMAGE RECONSTRUCITON

- 3D, 4D & 5D Reconstruction methods for special data acquisition geometries and strategies
  - Special analytical and iterative reconstruction methods that provide
    - Good signal-to-noise ratio
    - Accurate 3D volume information
    - Accurate 4D dynamic and/or functional information
      - Cardiac, respiratory gated images
      - biokinetics information
    - Accurate 5D physiological information and parametric information (?)
      - Additional biokinetics parameters, e.g., uptake, washout & exchange rates

FUTURE RESEARCH NEEDS IN DATA/IMAGE RECONSTRUCITON

- Reconstruction methods that compensates for image degrading factors
  - Iterative image reconstruction algorithms
    - Good sign-to-noise and other properties
  - Accurate models of physics of imaging process
  - Reconstruction with time-of-flight information
  - Motion compensation methods
    - Involuntary motions, e.g., cardiac, respiration
    - Patient motions
    - Free motions (?)

FUTURE RESEARCH NEEDS IN DATA/IMAGE RECONSTRUCITON

- Parameter estimation and calibration methods for high-resolution image reconstructions
  - Essential for high-resolution imaging (e.g., molecular imaging) methods
  - Solutions of multi-parameter estimate problems
  - Accurate and robust calibration methods
  - Implementation in high-resolution reconstruction methods
  - Automatic calibration/reconstruction (?)

FUTURE RESEARCH NEEDS IN DATA/IMAGE RECONSTRUCITON

- Validation/Evaluation methods --- Simulation tools
  - 4D realistic computer generated phantoms
    - Accurate models of anatomy, physiology, and attenuation, radioactivity, ρ, T1 and T2 distributions
    - Family of phantoms with simulated patient variations
  - Accurate Monte Carlo simulation methods with accurate models of
    - imaging geometries
    - imaging instrumentation
    - physics of imaging process
  - High-speed computational hardware
    - Low-cost computer clusters
  - Simulated patient studies (?)

ACKNOWLEDGEMENT

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